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Properties of QSO-Intrinsic Narrow Ultraviolet Absorption

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Abstract. I present the current state of knowledge about narrow ($\lesssim 500$ km s^{-1}) ultraviolet absorption that is intrinsic to QSOs. I consider interpretations in the context of the accretion-disk/wind scenario of QSOs.

1. Introduction

In the past four years, the study of truly intrinsic narrow absorption has exploded both as a result of new insights about how to identify these systems and because of the advent high resolution spectroscopy with large ground-based telescopes. Before summarizing the work and attempting to understand it in a coherent scenario, I start with a few conventions regarding nomenclature. A narrow absorption line nominally is one in which resonant UV doublets are well separated (Hamann & Ferland 1999). This implies widths less than about 500 km s^{-1} in order to resolve the C IV$\lambda\lambda1548, 1550$ doublet. I use the term NALs to refer to narrow absorption lines (in general) and NALQSO to refer to any QSO that has truly intrinsic narrow absorption (by analogy with the term BALQSO). I also use the term "associated" absorption lines as signifying that the absorption lies within 5000 km s^{-1} of the QSO emission redshift. (Note that an associated absorption line need not be intrinsic to the QSO.) Furthermore, a strong system is one whose C IV rest-frame equivalent width is larger than 1–2 Å. First, I will consider how we can identify intrinsic systems – that is, how we separate them from intervening gas. I will then discuss separately what we know from studies at high redshift and at low redshift. Finally, I will unify observed properties in the context of the accretion-disk/wind scenario.

2. Identifying Intrinsic NALs

There are two basic methods which one uses to infer the properties of intrinsic narrow absorbers. One can identify large populations of absorbers in a sample and consider if their is a relationship with the host QSO. Identifying populations of intrinsic absorbers typically involves a demonstration that there is an excess of absorbing systems over what is expected in a given redshift or velocity path. As a consequence, it is now known which systems are actually intrinsic.

Alternatively, one can identify a specific absorber as intrinsic and decipher the physical conditions of the gas. Identifying specific intrinsic absorbers requires either multiple epochs of observation to look for time variability and/or high

resolution spectroscopy to show that the absorbing gas only partly occults the QSO central engine.

Thus far, only fifteen QSOs have been shown conclusively to have intrinsic NALs through time variability and/or partial coverage. Of these, nine are radio-quiet, five are radio-loud, and only one is at low redshift. Six have been shown to be time variable (TV) while ten have been shown to exhibit the signature of partial coverage (PC). These are listed in Table 1 along with the citation to the work that showed the intrinsic origin.

Table 1. Known NALQSOs

Name	$z_{\rm em}$	Radio	Method	Reference
Q 0123 + 257	2.358	Loud	PC	Barlow & Sargent (1997)
Q 0150 − 203	2.139	Loud	PC, TV	Hamann et al. (1997a)
PKS 0424 − 131	2.166	Loud	PC	Petitjean, Rauch, & Carswell (1994)
Q 0449 − 134	3.093	Quiet	PC	Barlow, Hamann, & Sargent (1997)
Q 0450 − 132	2.253	Quiet	PC	Ganguly et al. (1999)
Q 0835 + 580	1.534	Loud	TV	Aldcroft, Bechtold, & Foltz (1997)
Q 0935 + 417	1.980	Quiet	TV	Hamann et al. (1997b)
PKS 1157 + 014	1.986	Loud	TV	Aldcroft, Bechtold, & Foltz (1997)
PG 1222 + 228	2.038	Quiet	PC	Ganguly et al. (1999)
PG 1329 + 412	1.930	Quiet	PC	Ganguly et al. (1999)
HS 1700 + 6416	2.722	Quiet	PC, TV	Barlow, Hamann, & Sargent (1997)
Q 2116 − 358	2.341	Quiet	PC	Wampler, Bergeron, & Petitjean (1993)
QSO J2233 − 606	2.238	...	PC	Petitjean & Srianand (1999)
MRC 2251 − 178	0.066	Loud	TV	Ganguly, Charlton, & Eracleous (2001b)
Q 2343 + 125	2.515	Quiet	PC, TV	Hamann et al. (1997c)

3. Intrinsic NALs at High Redshift

At high redshift, since the rest-frame ultraviolet transitions are shifted into the optical, we can take advantage of optical spectroscopy with large ground-based telescopes to identify specific absorbing systems as intrinsic. Unfortunately, since the QSOs are at higher redshift, it is generally more difficult to obtain detailed multiwavelength information about the QSOs themselves.

Strong systems seem to prefer optically-faint (OF), radio-loud QSOs with steep radio spectra (Foltz et al. 1986; Anderson et al. 1987; Møller & Jakobsen 1987; Foltz et al. 1988). In addition, the equivalent width of strong systems seems to correlate with orientation, with stronger systems existing in more radio-lobe dominated (that is, edge-on) QSOs (Barthel, Tytler, & Vestergaard 1997;

Baker et al., these proceedings). A recent study of QSO absorption systems down to a 0.15 Å limiting equivalent width also found that intrinsic systems can appear at very large "ejection" velocities (Richards et al. 1999, Richards 2001). This happens more so in radio-quiet QSOs than radio-loud QSOs and more so in flat-spectrum, radio-loud (FSRL) QSOs than steep-spectrum, radio-loud (SSRL) QSOs.

4. Intrinsic NALs at Low Redshift

At low redshift, we have the advantage of knowing very well the QSO properties. However, it is harder to identify intrinsic systems since we must rely on smaller space-based telescopes (*HST* and *FUSE*). High-resolution spectra can be obtained for only the brightest targets.

The first remarkable property of low-redshift NALQSOs is that none host strong systems (Ganguly et al. 2001a). As a result, the correlations with QSO properties seen at high redshift, which were driven by strong absorption, are largely absent. [Strong systems seem to exist in compact, steep-spectrum (CSS) radio-loud QSOs down to $z_{\rm em} \sim 0.7$ (Baker et al., these proceedings).] The equivalent widths of weak systems do not correlate with any single QSOs property but their velocity distribution seems to peak at the same velocity as the broad emission lines. This seems to indicate a relationship between the line-of-sight velocity of the absorbers and the velocity of maximum emissivity of the broad line region. A multivariate analysis of associated absorption indicates a combination of QSO properties that seem to prohibit the detection of associated NAL gas. Associated NALs are absent in FSRL QSOs that have mediocre C IV emission FWHM ($\lesssim 6000$ km s^{-1}), but are present in a finite fraction of FSRL QSOs with large C IV FWHM.

Table 2. Properties of QSO-Intrinsic NALs

$z_{\rm em} \gtrsim 1$	$z_{\rm em} \lesssim 1$
Strong systems	
• Prefer OF SSRL QSOs • EW correlated with orientation • Velocity distribution peaks with BEL, not $z_{\rm sys}$ • Exist at high $v_{\rm ej}$	• Largely absent @ $z \lesssim 0.7$ but exist in CSS RL QSOs @ $z \gtrsim 0.7$
Weak systems	
• No preference for RL • Excess of high $v_{\rm ej}$ NALs in RQs compared to RLs, and FSRLs compared to SSRLs	• Absent in FSRL QSOs with C IV BEL FWHM $\lesssim 6000$ km s^{-1} • Velocity distribution peaks with BEL, not systemic velocity • Enhanced probability of NALs in BALQSOs

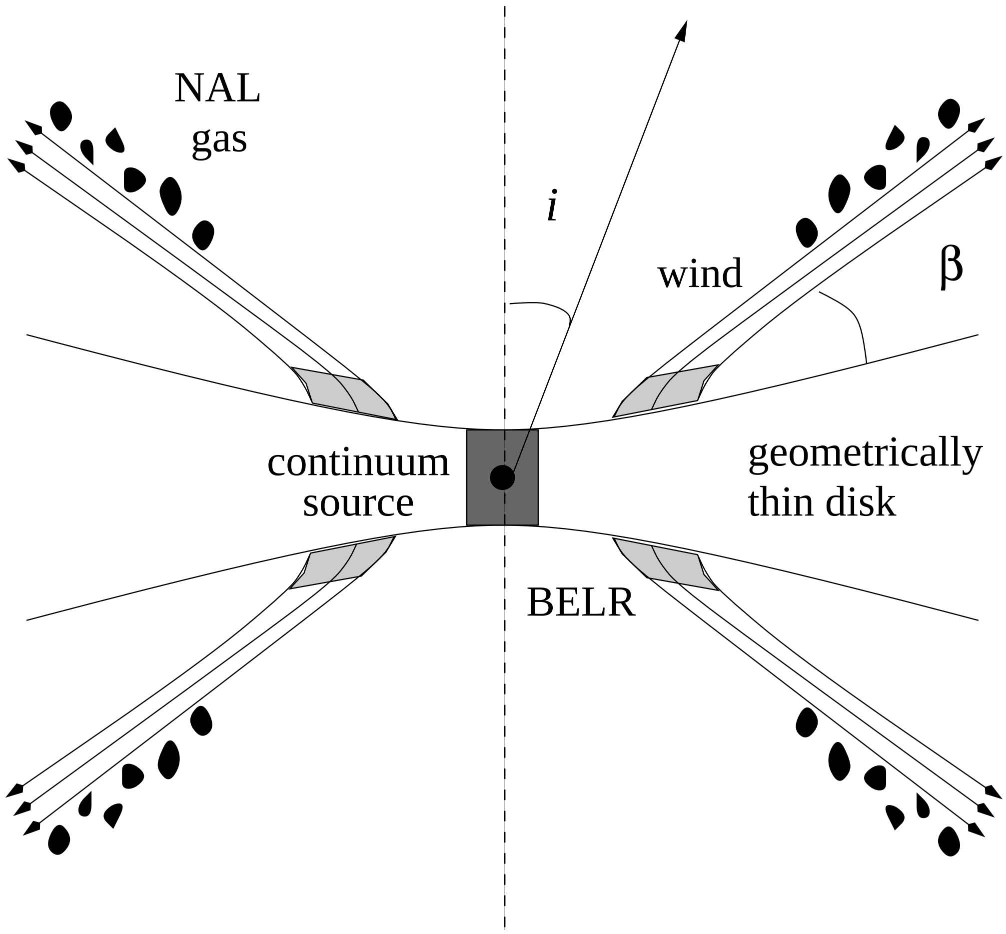

Figure 1. Disk-wind model for QSOs from Ganguly et al. (2001a). The inclination angle, i, and the wind opening angle, β, are shown.

5. Putting It All Together

These properties are summarized in Table 2, which is broken up according to both redshift and absorption strength. If we postulate that a unified model exists, there are three basic conclusions to draw from the table. First, there has been evolution such that strong systems are largely absent at low redshift. Second, the properties of weak absorbers at both, high and low redshift complement each other so that no evolution in their population is required. That is, the properties at both high and low redshift can be considered together as governing an unevolving population of absorbers. Similarly, the properties of high redshift strong systems and low redshift weak systems do not contradict each other and can be considered simultaneously.

We can understand these properties in the context of the disk-wind scenario. A cartoon of this scenario, from Ganguly et al. (2001a), is shown in Fig. 1. The scenario, a modification of the Murray et al. (1995) model originally employed

to explain broad absorption lines, is that of a radiatively driven, outflowing wind in which clumps of gas hug the wind at "large" distances from the black hole. Hydrodynamic simulations by Proga, Stone, & Kallman (2000) show that such clumps do arise from Kelvin-Helmholtz shearing instabilities.

This scenario has, essentially three fundamental parameters: the black hole mass, the mass fueling rate, and the inclination with respect to the observer. The black hole mass and mass fueling rate can also be translated into a wind opening angle and wind density. A given black hole mass implies a maximum mass accretion rate (that is, the Eddington rate). For a larger mass fueling rate, this implies a larger wind density. Moreover, the luminosity of the QSO will be larger and thus the acceleration of the wind will be even more dominated by its radial component. This will result in a smaller wind opening angle.

If we hypothesize that the wind in radio-loud QSOs is less dense than in radio-quiet QSOs, then strong NALs can be thought of as the analogues of BAL, where the wind itself is the source of absorption. Reversing the above reasoning, a sparser wind implies a less luminous QSO, explaining the preference for "optically faint" QSOs. The projected velocity dispersion of the wind along sightlines is small (i.e. narrow). Likewise, the optical depth of the wind is largest when the QSO is viewed at higher inclination angle (similar to BALQSOs).

The evolution of strong systems can be viewed as a change in the mass outflow rate (or wind density). This change can result either from a decrease in the mass fueling rate or an increase in the mass accretion rate. Either case seems natural since (1) there is only a finite amount of gas to fuel the engine and (2) over the duty cycle of the QSOs life, the accretion process will increase the black hole mass, and therefore the maximum allowed accretion rate.

The absence of weak associated systems in FSRL QSOs w/ average CIV FWHM can be seen as mostly an inclination effect. If the population of weak absorbers is due the clumps produced by the shear, then NALs will only be detected when the line of sight intercept these clumps. The flat-spectrum radio-loud QSOs in the Ganguly et al. (2001) sample were also strongly radio core dominated. So, there is little doubt that the QSOs are viewed at small inclination angles (i.e. face-on geometries). In addition, the width of the C IV emission line implies that the velocity dispersion of the wind along the line of sight is not large. Thus, the wind opening angle is "small." In this case, neither photons from the compact continuum, nor photons from the broad emission line region intercept the weak NAL clouds.

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